

# Solving Problems of Vibration Control

By **DONALD H. VANCE**, *Executive Engineer*  
and **R. L. BOOTH**, *Chief Engineer, The Korfund Co., Inc.*



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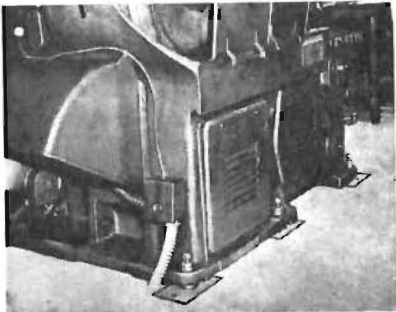
# Solving Problems of Vibration Control

**Vibration isolation is now a practical, economical necessity . . . Among advantages derived from correctly-designed control are increased machine output, reduced work spoilage, reduced construction costs . . . reduced maintenance costs . . . More efficient plant layout and improved worker health also benefits . . . Case studies covered in this two-part article**

**By R. L. BOOTH, Chief Engineer and  
DONALD H. VANCE, Executive Engineer, The Korfund Co., Inc.\***

**V**IBRATION transmission was once considered a necessary evil inherent in the operation of most machines, but advancement of the theory of vibration isolation and development of cork, rubber and steel-spring vibration isolators have now made possible better operation of all types of machines without vibration transmission.

As a result of experience and development originating from scientific application to thousands of machines, vibration isolation is now a practical, economical necessity as indicated by the fact that consulting engineers, after studying all the economic and



**Fig. 1. External vibration which may result in inaccurate work is isolated from this precision grinder**

engineering aspects of a proposed installation, are specifying vibration isolation for more and more installations. The owner of a machine whose operation creates vibration can now expect the following benefits from efficient, correctly-engineered vibration control: 1. Increased machine output; 2. Reduced work spoilage; 3. Reduced building and foundation construction costs; 4. Reduced maintenance costs; 5. More efficient plant lay-out; 6. Improved worker safety and health.

Increased output frequently results when it is possible to increase the

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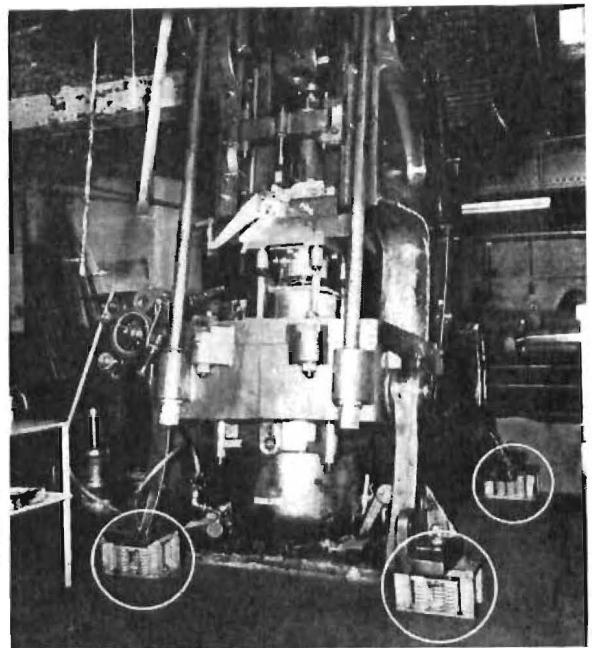
operating speed of an isolated machine without the danger of vibration transmission to the building and other nearby machines. There have been cases where horizontal reciprocating compressors could not be brought up to maximum speed when mounted on unisolated foundations because of extremely severe vibration set up in the building. The use of an isolated foundation makes it possible to operate any machine at the maximum speed recommended by the manufacturer without danger of vibration transmission.

Furthermore, based upon tests which have been made, some foundation authorities estimate that as much as 10 per cent of the energy delivered to a machine is expended in vibrating the machine foundation, the soil around the foundation and the building. The writers have encountered cases where this transmitted vibration was severe enough to be felt  $\frac{1}{2}$  mile away from the vibrating machine. This waste of machine energy can be greatly reduced by the use of properly-engineered vibration control for preventing transmission of forces from the machine foundation.

Thousands of dollars are spent to produce extreme accuracy in such machines as surface and cylindrical

grinders, jig borers and other precision equipment. Yet many plant engineers have seen the work of these machines ruined because external vibration jarred the machine and produced flaws in the work. An extremely expensive example of this waste is often encountered in the precision grinding of the hardened steel rolls for paper mills where external vibration frequently ruins the surface on a roll which may be 20 ft. long and 4 ft. in diameter, unless the roll grinder is mounted on an isolated foundation. Isolation against external vibration for precision machinery is being widely adopted, and Fig. 1 shows one such installation under a precision grinder.

"Chattering"—vibration of the machine itself—frequently produces work spoilage on the vibrating machine, or, if the machine is un-isolated, this vibration may be transmitted to

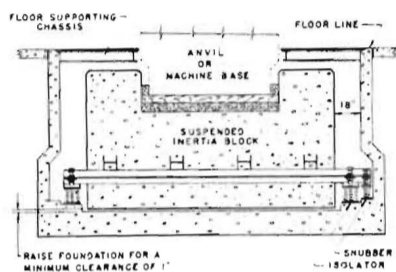


**Fig. 2. Even large punch presses, when properly isolated, will not transmit vibration to the floor**

other machinery where it destroys the accuracy of the operation of these machines. Here again, properly designed vibration isolation provides the solution to this problem.

Worker fatigue resulting from continuous subjection to vibration and shock from impact machinery is another important factor contributing to work spoilage. Nerves and muscles become tired under the strain of repeated vibration and it is impossible for the worker to continue doing accurate, efficient work. An example of this has been found with many punch press and hammer operators who have to rapidly and accurately insert material in the dies before each blow is struck. At the end of the day, work spoilage has increased considerably because the workers' coordination has been impaired by vibration fatigue.

Vibration isolation for machinery may save many times the cost of the



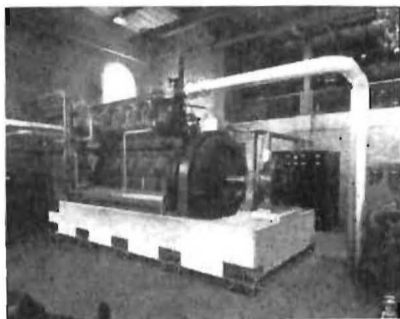
**Fig. 3. An installation similar to this resulted in large savings for an automotive parts manufacturer**

isolators in building construction costs alone. For example, tests and experience have shown that when even large punch presses are properly isolated as shown in Fig. 2 there is no shock transmission to the floor, and consequently the floor must support only the static load of the machine. When designing a new building, tremendous savings can be made through the use of lighter construction, and vibrating machinery can be safely located in existing buildings where the floor strength would not be sufficient if it were necessary to provide for shock loads.

A very interesting example of savings made possible by efficient vibration control recently occurred at the plant of a large Mid-Western manufacturer of airplane and automotive parts. This company found that the vibration from its forging hammers was seriously affecting the accuracy of precision machines. Plans had been drawn up for an expensive new forge building in order to move the hammers away from the other equipment. Before going to the expense of new

**Fig. 6. These hammer mills repeatedly ripped off their foundation bolts until they were mounted resiliently**

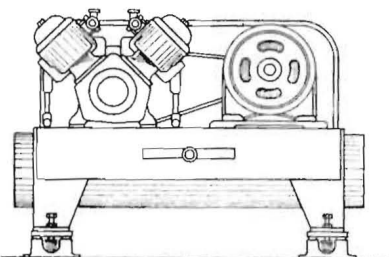
construction, it was decided to first try mounting one of the hammers on a spring isolated concrete foundation in the old building. A foundation arrangement similar to that shown in Fig. 3 was used and the results were so excellent that it was impossible to detect any transmitted vibration even with a sensitive vibrometer placed beside the spring isolated foundation. This made it possible to abandon



**Fig. 4. A spring-isolated foundation similar to this one saved a Cuban building from being wrecked by transmitted vibration**

plans for the new building and five hammers have already been installed on isolated foundations with four more underway.

It is also frequently possible to effect savings by reducing the customary machine foundation size. For example, it is unnecessary to increase the mass of an isolated foundation because bad soil factors are encountered since the installation can be pre-designed so that there will be no vibration transmission from the foundation into the soil. Another example is often encountered in engine founda-

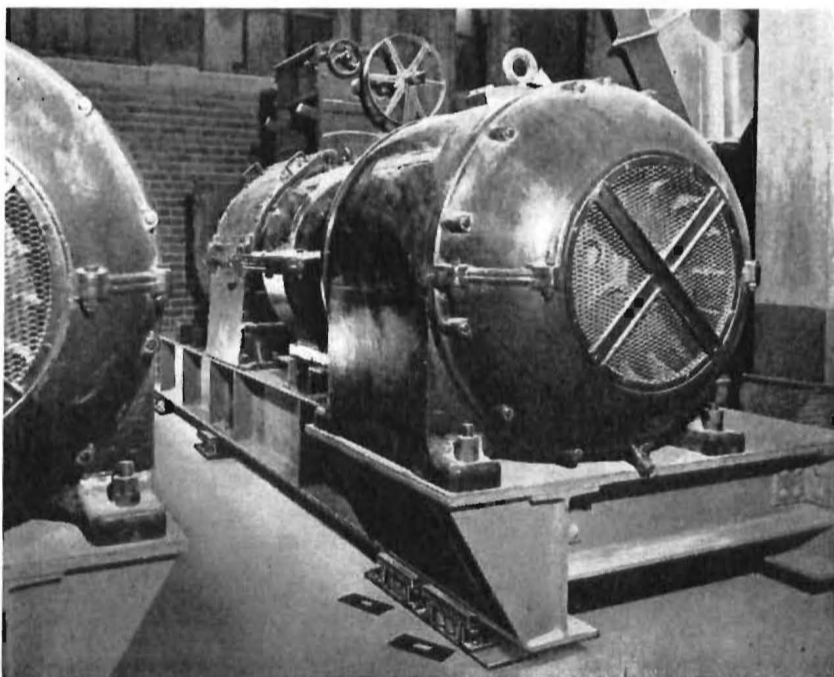


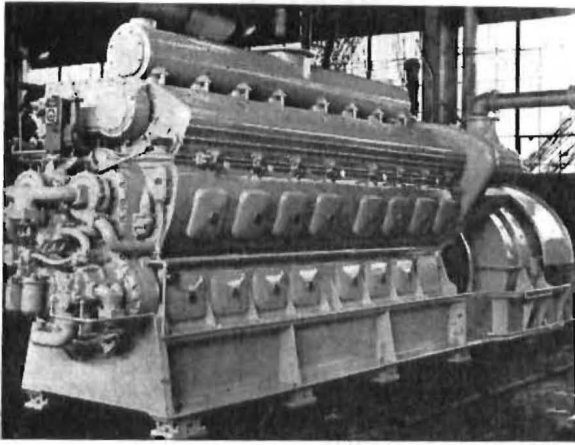
**Fig. 5. Typical arrangement of a small high-speed reciprocating compressor-condenser unit on spring isolators**

tions where it is frequently found that the size of the foundation can be reduced by 25 per cent or more when vibration isolation is incorporated. This is particularly beneficial where space limitations prevail or where a larger foundation entails excavation into bedrock, etc.

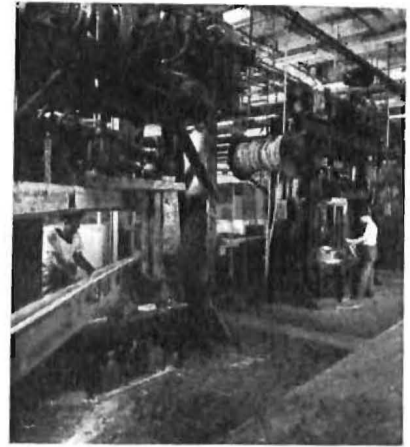
One of the most outstanding advantages of properly-engineered vibration control is the tremendous reduction in maintenance cost which results from elimination of vibration transmission. The writers are familiar with many cases where machine vibration was actually destroying the building. One interesting case occurred in Havana, Cuba, where the frequency of the transmitted vibration from a large engine coincided with the natural frequency of a building wall across the street. Resonance vibration was set up in this wall and it cracked as the result. A properly designed spring isolated foundation such as one shown in Fig. 4 provided a highly satisfactory solution to this problem.

Another interesting example occurred just recently when vibration from a compressor traveled down





**Fig. 7—Left. Here is a typical high-speed engine-generator set which is resiliently mounted**



**Fig. 8—Right. It was necessary to isolate these drop hammers because of the nearness of precision finishing machines**

through the building to a restaurant five floors below. The frequency of this vibration coincided with the natural frequency of large chandelier over a table in the restaurant. This resonance vibration produced in the chandelier was of extreme magnitude and caused it to fall. Further danger of vibration transmission was completely eliminated by the use of an arrangement similar to Fig. 5.

Vibration from one machine may be highly destructive to another machine. For example, the offices of a large company employing forging hammers are located very close to these hammers. The shock from the hammers completely upset the accuracy of the tabulating machines and necessitated frequent repairs until the machines were isolated against this vibration. Figure 6 shows two hammer mills which repeatedly ripped off their foundation bolts and transmitted extreme vibration before being mounted resiliently as shown. Another example of machine vibration destructive to itself was encountered by one of the writers on a number of engine-generator installations for the U. S. Navy. Due to stresses set up in the engine base by vibration, the

castings cracked as fast as they were welded. Resiliently mounting these generator sets relieved the stresses and prevented further failures. A typical high-speed engine-generator installation is shown in Fig. 7.

At the outset of the war it was imperative that mass production on an "assembly line" be established in the aircraft industry. This presented tremendous difficulties because drop hammers could not usually be located close to precision finishing machines due to the vibration created. Mounting the hammers on spring isolated foundations made it possible to adopt efficient plant layout as shown in Fig. 8 and to locate the hammers right in the production line beside the most sensitive equipment, without difficulty.

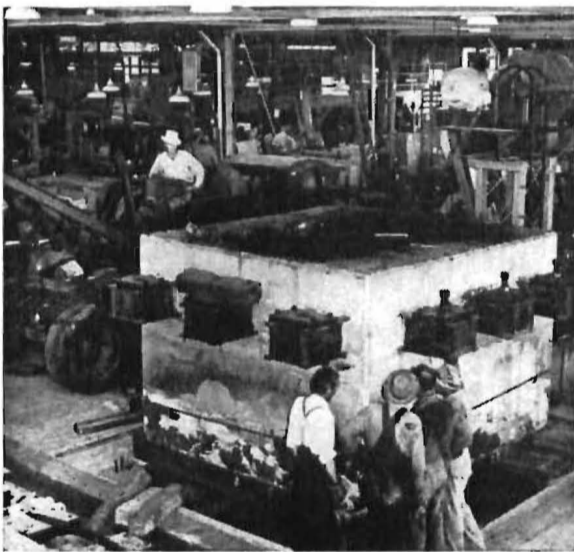
An interesting example occurred on several occasions where it was found that one aircraft plant had a surplus of hammers whereas another had a serious shortage. *The hammer and its foundation* with the isolators attached were lifted out of the pit at one plant, placed on a flat car and shipped to the second plant for immediate installation and renewed

production. Figure 9 shows one of the foundation blocks being lowered into position.

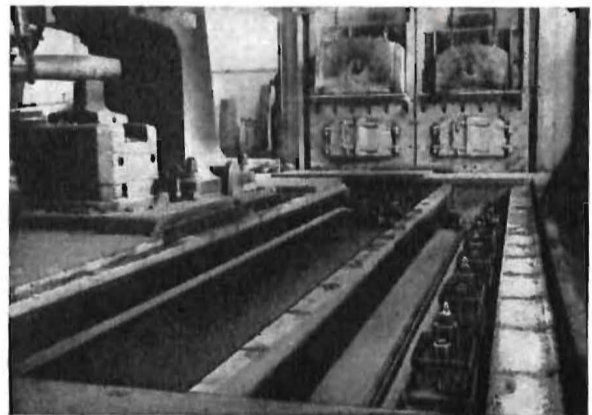
The forging industry has always had difficulty with vibration from hammers loosening the firebrick in the arches of the forging furnaces and causing bricks to fall. Rebuilding the furnaces, an expensive proposition, has been entirely eliminated by the arrangement shown in Fig. 10 where it will be noted that a forging hammer and a forging furnace are located side by side without vibration transmission from the hammer to the furnace.

In chemical processing plants, it is frequently desirable to locate separators, pulverizers, and other types of vibrating machinery high in the building in order to permit a "gravity flow" of the material down from one floor to another of the plant. This frequently entails installation of the equipment on steel beams or on platforms far above the floor where it is quite difficult to design a structure rugged enough to withstand vibration transmission. Here again, vibration isolation permits this procedure.

With properly designed vibration control available for all types of ma-



**Fig. 9—Left. Hammer foundation blocks are being lowered into place with the isolators installed**



**Fig. 10—Below. Firebrick in the arches of the furnaces in the background was continually being shaken loose until hammer foundations were isolated**

chinery, the plant engineer can locate his equipment wherever he chooses for maximum production efficiency without vibration from one machine interfering with operation of another.

Efficient vibration control can produce savings through reduction in worker absenteeism and accidents. Uncontrolled vibration produces a

very definite strain upon employee's nerves and results in fatigue which frequently leads to accidents. The type of severe shock associated with punch press, hammer and other impact machinery operation is particularly injurious to workers' kidneys, and after these machines are resiliently mounted to prevent vibration

transmission, rapid improvement in the operators' health generally results. Naturally it is also impossible for office employees to work and maintain a healthy mental attitude when subjected to the annoyance of vibration transmitted through the building structure from machinery to the offices.

## Solving Problems of Vibration Control—II

By DONALD H. VANCE, Executive Engineer  
and R. L. BOOTH, Chief Engineer, The Korfund Co., Inc.

THE FIRST portion of this article has been devoted to a discussion of a few of the benefits of vibration control. In Part II, vibration isolation for various types of equipment will be discussed. However, it should be pointed out that it is practically impossible to give a specific solution to each type of equipment vibration since there are many factors varying with each job which must be considered when selecting the proper isolation material and designing the isolated foundation. Nevertheless, the following discussion and illustrations are indicative of the general types of solutions which have been developed.

Engines, turbines, motor-generator sets, compressors, blowers and similar types of equipment creating steady-state vibration of a definite known frequency can be effectively isolated with either springs, rubber or cork, depending upon the type of foundation, building construction, location of equipment, and characteristics of the equipment such as speed, frequency of disturbing vibration and weight, all of which have to be given careful consideration when the proper isolation material is selected.

For such equipment as slow-speed engine-generator sets, large reciprocating compressors, pulverizers, etc. It is usually desirable to add a concrete foundation isolated from the

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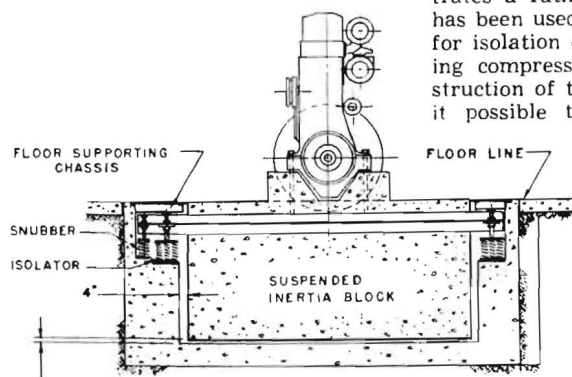


Fig. 11. Arrangement for large, slow-speed diesel generator sets

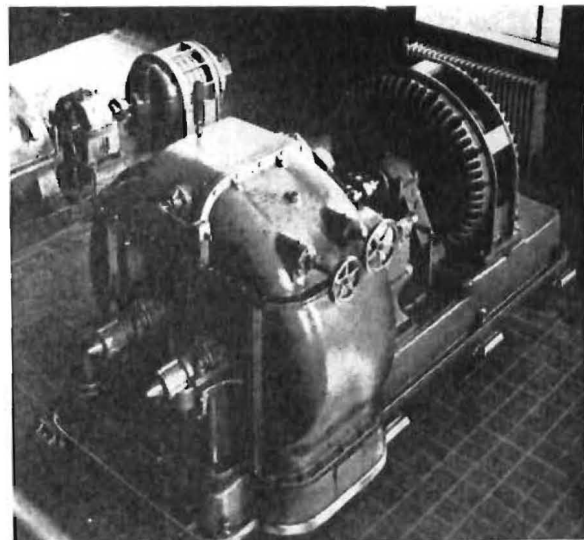


Fig. 13. Where machines are more nearly dynamically balanced the inertia mass may be omitted

building structure in order to provide sufficient inertia mass to make the installation satisfactory from the standpoint of stability as well as vibration control. Proper design of the isolated inertia mass to prevent excessive movement of the installation is of extreme importance, particularly where piping connections are in use.

Figure 11 shows a typical arrangement for large slow-speed diesel-generator sets where the equipment is mounted on a spring-isolated concrete foundation. Figure 12 illustrates a rather unique design which has been used with very good success for isolation of horizontal reciprocating compressors. The patented construction of the material used makes it possible to incorporate just the

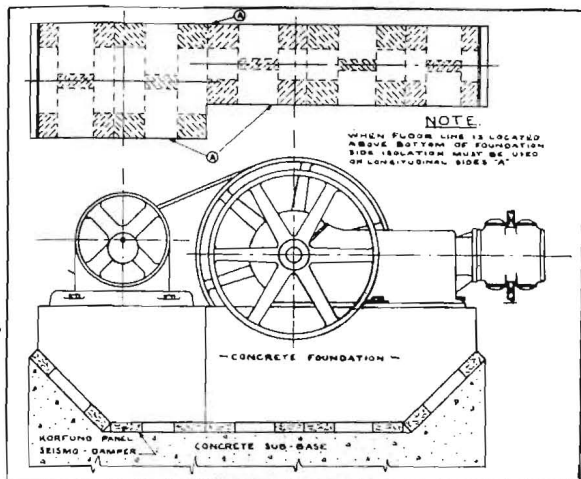
proper amount of cork in order to secure an optimum loading and to locate the cork accurately with respect to the center of gravity of the installation.

Where machines are more nearly dynamically balanced, the inertia mass can be omitted as illustrated in Fig. 13 showing a large motor-driven blower mounted directly on spring-type isolators. Large piping connections with their flexible joints occur below the floorline.

High-speed engine-generator sets and the smaller reciprocating compressors are generally mounted directly on the isolation material (as shown in Figures 5 and 7, Part I).

There are many other types of equipment in this category which are either mounted on carefully designed isolated inertia masses if the unbalanced machine forces are large or are mounted directly on selected types of isolation materials if the speeds are higher and the equipment is well-balanced.

The determination of the type of resilient mounting, size of foundation and other factors in the case of heavy impact machinery requires individual

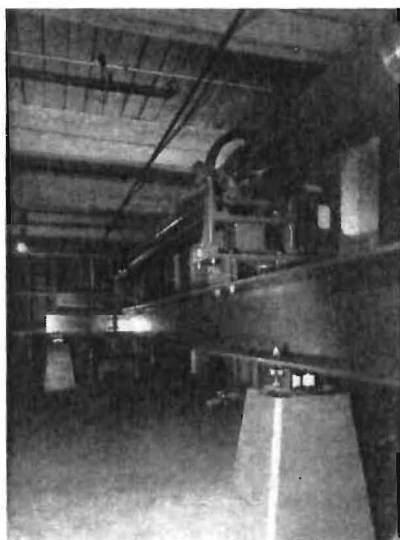


**Fig. 12. This design has been found effective for use with horizontal reciprocating compressors**

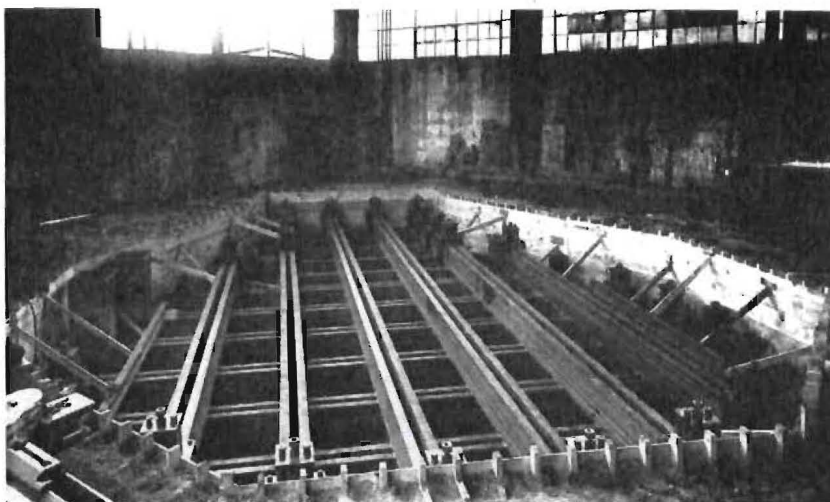
in order to protect the less expensive furnaces, flame tables, etc. Nevertheless, this source of vibration will result in reduced profit due to expensive maintenance costs and work spoilage, and negative isolation for this latter auxiliary equipment generally represents an economical money-saving investment. Because of the long life expected and the service requirements in this type of industry a sturdy steel spring type of mounting is required.

Certain types of presses require isolation in the same manner as described above for hammers. In general, however, a press usually has sufficient inertia mass in its own frame so that a concrete foundation is not required to obtain operating stability and efficient shock control.

study and thorough analysis due to the many variable factors involved. Complex equations have been derived and tested whereby the action of such an installation can be accurately predetermined. In general, a most efficient impact machine installation is made by suspending the machine and its concrete foundation on spring isolators as illustrated in Fig. 3, Part I. In this type of suspension a sufficient amount of concrete is used to act as an inertia mass which will limit vertical motion of the block under maximum impact to a predetermined amount considered satisfactory for the operation of the particular machine involved. The spring mountings then absorb shock, changing its form to that of a more slowly applied force to the outside structure. In many cases where actual tests have been conducted with large forging hammers in operation it was impossible to obtain any indication of shock or vibration transmission from the hammer to the adjacent pit wall.



**Fig. 14. Special negative isolation has been designed for this job in order to protect the accuracy of an optical lens measuring instrument**



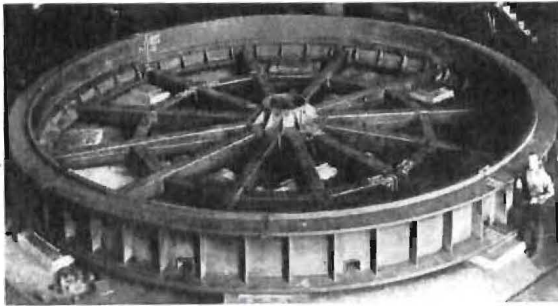
**Fig. 15. This is an interesting installation where a very large machine is mounted on a spring-isolated foundation**

Another advantage of the adjustable spring type method of mounting is the ability to level the hammer at any time in case of possible uneven settlement of the outer concrete pit, which is impossible if an un-isolated hammer foundation settles. This adjustment can be made at any time without taking the hammer out of operation by simply making a few extra turns on the isolator adjustment bolts.

In existing forge shops and other heavy machinery plants where it is necessary to use pre-heat and heat treating furnaces, flame cutting tables, layout tables, etc., close to a source of heavy shock such as adjacent to forging hammers, it has been found that the shock transmission causes collapse of arches and walls, inaccuracies in the work performed by flame cutting equipment, and disturbances in layout tables. Where the heavy equipment creating the shock disturbance is already in place and where several such disturbing machines are in operation, it would, of course, be an extremely expensive job to isolate all of this equipment

Impact machinery used in the metal forming industry, such as punch presses, shears and brakes can be efficiently isolated even on upper stories of a building by use of properly designed spring type mountings. Figure 2, Part I, illustrates the most common arrangement. In some cases where the height of the machine is large in comparison to the area of its base, an extended structural steel or other type of base covering a greater floor area than occupied by the machine itself may be required in order to provide the necessary machine stability, as well as to spread the weight over a sufficient floor area to fall within allowable static load limits.

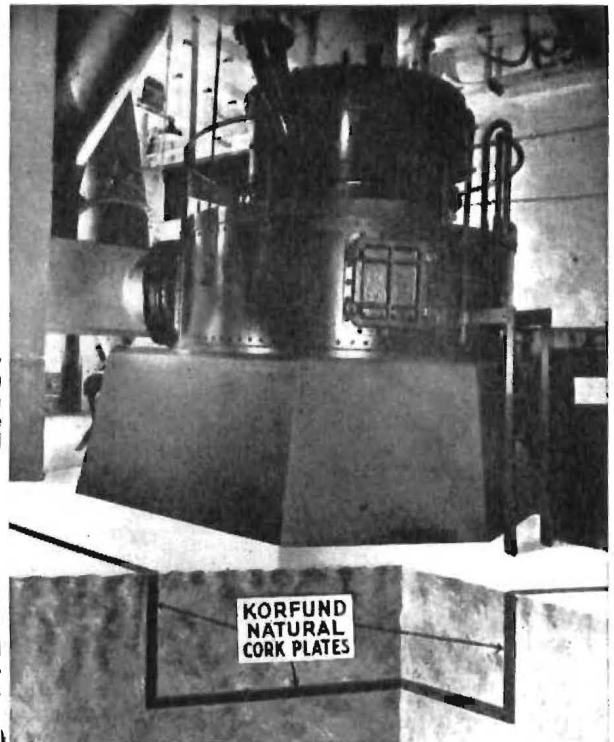
Machine tools can either be the cause of vibration disturbance or they may have to be protected against external vibration. The effect of vibration on the latter type of machine tools such as grinders, jig borers, etc. can result in costly work spoilage and damage to the machine. In most cases there are many sources of vibration disturbance and shock with a resulting wide variation in disturbing



frequency. It is therefore usually necessary to provide an isolation material with a large static deflection to isolate against low steady-state vibration as well as intermittent shock. Due to the large deflection requirements of the isolation material it is usually necessary to incorporate a spring type mounting to obtain a practical design. Figure 1, Part I, illustrates a precision grinder protected from vibration interference by use of steel spring type isolators, which in this particular case are recessed into the floor to keep the height of the installation at a minimum.

Machine tools which are often a source of vibration, such as broaching machines, milling machines, shapers and planers, can be located close to precision machines and sensitive laboratory equipment without fear of vibration disturbance if properly isolated. Cork and rubber mountings have been used under this type of equipment with considerable success but here also as in practically all cases the type of structure upon which the equipment is mounted is an important factor. A vibration creating machine tool mounted on a two or three inch thickness of cork located in a sturdy reinforced concrete building can usually be expected to operate without the slightest vibration disturbance while the same machine mounted in the same manner in a wood frame constructed building might be the cause of a great deal of vibration disturbance. In the case of the latter installation a comparatively soft spring mounting or a combination spring and rubber mounting may be required for high efficiency. Figures 15 and 16 show a very inter-

**Fig. 16. Above: Another installation similar to the one shown in Fig. 15. The part shown weighed 46 tons**



**Fig. 17. Right: Coal pulverizers are generally isolated in this manner**

esting installation where a very large machine used for cutting naval gun turret gears up to 60 ft in diameter is mounted on a spring isolated foundation. The total supported weight is over one million pounds.

It is often found advantageous to locate sensitive testing equipment and precision measuring devices in a locality where vibration disturbance from an outside source is to be expected. The set up may be of a temporary nature or portable unit and it would therefore be impractical to attempt to eliminate the source of vibration. On the other hand, the installation may be of a permanent nature located in a plant having many sources of vibration or even a single source of vibration but where the expense of isolating the disturbance at its source may be unwarranted.

In these cases it is desirable to isolate the sensitive equipment against the possibility of incoming vibration. Due to the many variables involved in an installation of this type it is

most always necessary to design a special type of mounting to suit the equipment under consideration. Figure 14 illustrates the application of special negative isolation designed to protect the delicate accuracy of an optical lens measuring instrument against incoming vibration. Generally speaking, it is usually necessary to provide considerable spring deflection in order to isolate against many vibration frequencies as well as shocks.

Just a few sample solutions to the thousands of vibration problems have been given above. However, scientific vibration control has now advanced to the point where there are extremely few machines which cannot be economically isolated against vibration transmission. Constant research is being carried on in this field and new and improved vibration control products are constantly being introduced to keep pace with the increasing demand for highly effective vibration and shock control.